ULTRASONICS

HOW DOES IT WORK?

The SONOZAP ultrasonic power supply (generator) converts DC voltage to high frequency 25 kHz (25,000 cylces per second) electrical energy. This electrical energy is transmitted to the transducer within the handpiece, where it is changed to mechanical vibrations. The vibrations from the transducer are intensified by the probe (horn), creating pressure waves in the liquid. This action forms millions of microscopic bubbles (cavities) which expand during the negative pressure excursion, and implode violently during the positive excursion. It is this phenomenon, referred to as cavitation, which produces the powerful shearing action at the probe tip, and causes the molecules in the liquid to become intensely agitated.

FREQUENCY AND AMPLITUDE

The radiating-wave frequencies most commonly used in ultrasonic cleaning, 18-120 kHz, lie just above the audible frequency range. In any sonic system,the harmonics of the fundamental frequency, together with vibrations originating at the container walls and liquid surface, produce audible sound. Thus, an operating system that is fundamentally ultrasonic will nonetheless by audible, and low frequency (20-kHz) systems will generally be noisier than higher-frequency (40-kHz) systems.

Moreover, ultrasonic intensity is an integral function of the frequency and amplitude of a radiating wave; therefore, a 20-kHz radiating wave will be approximately twice the intensity of a 40-kHz wave for any given average power output, and consequently the cavitation intensity resulting from a 20-kHz wave will be proportionately greater than that resulting from a 40-kHz wave.

The cavitation phenomenon will, of course, occur less frequently at 20 kHz, but this is not thought to have a significant bearing on effectiveness. However, the longer wavelengths of low-frequency ultrasonic systems result in substantially different standing-wave patters throughout the liquid medium.

The standing or stationary waves produced by ultrasonics in liquid media result from the simultaneous transmission of the surface-reflected wave motion and the wave motion originating at the transducer radiating surface. The fixed points of minimum amplitude are called nodes, and the points of maximum amplitude are called loops.

The distance between the nodes and loops of the 20-kHz standing wave (2 in.) will be approximately twice that of the 40-kHz wave. Because cavitation takes place primarily at the loops, the distance between cavitation sites will thus be larger with 20-kHz than with 40-kHz radiation, and the 20-kHz waves will also have larger dead zones (i.e., zones with little or no cavitation activity).

It is for this reason that work resulting from 20-kHz radiation is likely to be less homogeneous and less consistent, even though this frequency produces more intense cavitation. Much of the inhomogeneity in ultrasonic fields can, however, be reduced or wholly eliminated through the use of sweep frequencies, or radiating waves with a

multitude of different frequencies. By this means, several overlapping standing waves can be generated at the same time, thereby eliminating much of the dead zone.

The amplitude of the radiating wave is directly proportional to the electrical energy that is applied to the transducer. In order for cavitation to be produced in a liquid medium, the amplitude of the radiating wave must have a certain minimum value, which is usually rated in terms of electrical input power to the transducer. No cavitation can occur below this threshold value, and the use of electrical power over and above the minimum level results not in more intense cavitation activity but rather in an increase in the overall quantity of cavitation bubbles. The minimum power requirement for the production of cavitation varies greatly with the colligative properties and temperature of the liquid and with the nature and concentration of dissolved substances.

CAVITATION

If a sound wave is impressed upon a liquid and the intensity is increased, a point will be reached where cavitation occurs. Cavitation is the formation of a gas bubble in the liquid during the rarefaction cycle. When the compression cycle occurs the gas bubble collapses. During the collapse tremendous pressures are produced. The pressure may be of the order of several thousand atmospheres. Thousands of these small bubbles are formed in a small volume of the liquid. It is quite generally agreed that it is cavitation that produces most of the biological, detergent, mechanical, and chemical effects in the application of high intensity sound to various mediums.

The intensity with which cavitation takes place in a liquid medium varies greatly with the colligative properties of that medium, which include vapor pressure, surface tension, viscosity, and density, as well as any other property that is related to the number of atoms, ions, or molecules in the medium. In ultrasonic cleaning applications, the surface tension and the vapor pressure characteristics of the cleaning fluid play the most significant roles in determining cavitation intensity and, hence, cleaning effectiveness.

The energy required to form a cavitation bubble in a liquid is proportional to both surface tension and vapor pressure. Thus, the higher the surface tension of a liquid, the greater will be the energy that is required to produce a cavitation bubble, and, consequently, the greater will be the shock-wave energy that is produced when the bubble collapses. In pure water, for example, whose surface tension is about 72 dyne/cm, cavitation is produced only with great difficulty at ambient temperatures.

It is, however, produced with facility when a surface-active agent is added to the liquid, thus reducing the surface tension to about 30 dyne/cm. In the same manner, when the vapor pressure of a liquid is low, as is the case with cold water, cavitation is difficult to produce but becomes less and less so as temperature is increased. Every liquid, in fact, has a characteristic/temperature relationship in which cavitation exhibits maximum activity within a fairly narrow temperature range.

DISPERSION DUE TO ULTRASONICS

Dispersion in chemistry means the breaking down of a liquid or solid particle into smaller sizes or finer texture and distributing them in another medium.

In Chemistry the term system is applied to the whole mixture. Each of the substances comprising the system is called a component. A mixture of two substances is termed a two-component system. The form in which the component exists is called a phase, as, for example, gas, liquid, or solid. A colloidal solution is a two-component system in which a finely divided substance is uniformly distributed through the other. These systems may be classified according to the fineness of dispersion, as, for example, mechanical suspensions, colloidal solutions, and molecular solutions.

A list of two-component systems is given below:

Solid -Solid ,Solid- Liquid ,Solid- Gas ,Liquid -Solid, Liquid- Liquid ,Liquid -Gas, Gas-Solid and Gas- Liquid.

All of the above may be obtained in colloidal dimensions. However, liquid + solid and liquid + liquid have received the most attention. Intense sound fields may be used to bring about mixtures in the above systems.

EMULSIFICATION DUE TO ULTRASONICS

An emulsion is a suspension of fine particles or globules of a liquid in a liquid. Emulsions are generally produced by violent agitation. This suggests that ultrasonics may be used to produce emulsions.

If two immiscible liquids, such as water and gasoline, are placed in a container and subjected to intense sound vibrations it has been found than an emulsion will be formed.

The action of ultrasonics in producing emulsification can also be applied to the production of alloys of iron and lead, aluminum and lead, aluminum and cadmium, etc., which are not miscible in the liquid state. It is possible to keep the metals mixed by the application of ultrasonics up to the point of solidification. New bearing materials have been made in this way.

Ultrasonics have also been applied to photographic emulsions with an improvement in homogeneity and stability.

Ultrasonics have been applied to molten zinc, tin, and aluminum. It was found that the solidification occurred more quickly. In addition, the structure in the solidified state was found to be finer grained.

The homogenization of milk, that is, the reduction in size of the fact particles so that cream does not form while the milk stands, can be carried out by means of the application of ultrasonics.

COAGULATION DUE TO ULTRASONICS

In spite of the fact that ultrasonics have strong dispersive effects on liquid emulsions their effect on gas and solids and gas and liquids is the opposite - namely, coagulation. The solid and liquid particles in mist, dust, and smoke agglomerate when these mixtures are subjected to intense sound waves. the particles in a small smoke attack have been

coagulated and precipitated. The action depends in some degree on the wavelength and intensity.

Degassing of molten metals by the application of ultrasonics is another example of coagulation. Small bubbles form at first which join to form larger ones. The larger ones rise to the surface and are expelled. This use of ultrasonics should lead to an improvement in castings where the presence of bubbles is very objectionable.

CHEMICAL EFFECTS OF ULTRASONICS

A large number of experiments have been conducted on the effect of intense sound waves upon chemical reactions. Certain types of chemical reactions have been speeded by the application of intense waves. However, in some cases it is difficult to isolate the thermal effects due to the sound and the effects due to the sound alone. Another chemical effect is the breaking down of molecules. For example, a chain molecule of starch has been broken into six fragments. The application of intense sound waves to speed up the aging of whiskey has been suggested. the explanation is that in the aging process there is a gradual change in the structure of complex molecules which could be accomplished in a relatively short time with the application of sound.

BIOLOGICAL EFFECTS OF ULTRASONICS

Ultrasonics have a very destructive effect upon small living organisms. Small fish have been killed by high-power echo ranging and sounding devices.

Ultrasonics have been used in the extraction of antigens secreted in the cells of pathogenic bacteria. These antigens are used in serums for immunization against typhoid and other diseases. The bacterial cell walls are broken down by the application of ultrasonic waves and the antigens are set free. The cell walls of the bacteria are separated from the antigens by centrifuging.

It appears that bacteria can be destroyed by ultrasonics. The bacteria in milk have been reduced by the application of ultrasonics. This indicates that milk can be sterilized by ultrasonics.

Another application in medicine is the use of sound to produce stimulation within the body. Therapeutic effects of a different nature but similar to those produced by heat and radio-frequency diathermy may be obtained.

As in the case of chemical effects the biological effects are somewhat obscure but very interesting.

MEDICAL APPLICATIONS OF ULTRASONICS

The applications of ultrasonics in the medical field have involved analysis and treatment. The developments in the medical field appear to be very promising.

The effect of ultrasonics on tissues has been investigated. The heating and mechanical effects have been isolated. The conclusion is that there is an effect outside of the heating effect.

The effects of the changes produced by high intensity sound upon the central nervous system has been investigated. The results show that nerve cells are particularly sensitive to ultrasonics, while blood vessels and nerve fibers are much more resistant.

A study of the therapeutic effect of ultrasonics shows that the heat which is produced plays the major role. However, ultrasonics also produces a mechanical effect. Ultrasonics has been used to produce deep-seated heating in the treatment of arthritis.

The cerebral ventricular geometry has been portrayed by means of ultrasonic techniques. The head is immersed in water. An underwater projector sends an ultrasonic wave through the head. A hydrophone picks up the transmitted sound. A frequency of 2.5 megacycles was used. A scanning system together with a facsimile-type recorder presents the ultrasonogram in the form of a picture showing the cerebral ventricular geometry. This method provides a means for the detection of brain tumors similar to that of the X-ray.

Recent work on tumor detection employs ultrasonic waves and echo-ranging techniques with cathode-ray presentation. the pulses are sent into the body and the echos return in different intensities depending upon the difference in acoustical impedance of the malignant and nonmalignant tissues and in different times depending upon the depths of the reflecting boundaries.

A small version of the ultrasonic drill has been developed for use by dentists in drilling teeth. the advantages of the ultrasonic drill is reduction in pain and improved definition of the drilled area.

Destructive ultrasonic probes have been developed for medical use. These probes typically operate between 20 and 60 kilohertz, usually of the piezoelectric type and have high strokes at their distal ends.

One such probe is tubular in shape with a small frontal surface area. This surface area produces little or no cavitation when placed in water, however, due to high mechanical vibration this probe can cut through tissue and aspirate the emulsified particles through the center without damage to connective tissue.

Another tubular probe widely used for medical applications is the phacoemulsifier. The phacoemulsifier is used in ophthalmology for removing cataract lenses from ones eye. The same principal of mechanical action with little or no cavitation is present at the probes tip that actually cores the lens and aspirates it through the center.

Still another medical use of ultrasonics is cutting through tissue with a knife edge. Advantages of this technique for the patient is reduced bleeding from coagulation of blood vessels and the ease at which the knife blade cuts from reduced friction and increased sharpness.

THERMAL EFFECTS OF ULTRASONICS

There is considerable temperature rise in the ultrasonic field in a liquid. A rise of several degrees per minute can be obtained. The generation in heat is due to dissipation of the

sound by absorption in the liquid. The generation of head by the action of ultrasonics obscures the effects which can be attributed to sound alone because many chemical and biological phenomena observed when ultrasonics are applied are also obtained by the application of heat. The practical value of heating by ultrasonics remains to be seen.

ULTRASONICS AS A DETERGENT

Ultrasonics may be used to clean and wash various substances. Tests have been made of a ultrasonic washing machine in which clothes mixed with the conventional water and soap solutions are subjected to high intensity sound waves. It has been found that clothes can be cleaned as effectively in this way as by conventional means.

ULTRASONIC CLEANING AND DEGREASING

The use of ultrasonics for cleaning and degreasing surfaces has bound widespread use in industry. Cavitation reduces the surface tension of the clinging dirt and thereby produces a cleaning action on all surfaces and recesses. Cavitation emulsifies greases and oils and thereby assists in the removal of such coatings.

ULTRASONIC DRILLING

The drilling of glass, ceramics, and metals is now being done by means of ultrasonics. an ultrasonic generator for use in drilling is shown in Fig. 16.6. The tip sets up cavitation in a surrounding liquid-borne abrasive slurry. The forces produced by the cavitation bubbles propel the abrasive slurry against the material being drilled. The result is that glass, ceramics, and metals are penetrated in the matter of a few seconds. The point may be any shape as contrasted circular drills. The ultrasonic drill shown in Fig. 16.6 employs a magnetostriction transducer. The system operates as a half-wave resonator. The dimensions of the resonator are usually such that resonance occurs at 20 kilocycles. The amplitude at the drilling tip is increased by the use of a mechanical transformer in the form of a tapered rod.

ULTRASONIC SOLDERING

Aluminum is very difficult to solder because of the oxide which is formed on the surface. When cavitation is induced in the molten solder applied to the surface, the resultant forces break down the metal oxides formed on the surface of the parts being soldered. In this way, the solder is exposed to the pure base metal in a non- oxidizing atmosphere. The ultrasonic energy may be applied to a pot of molten solder or to the tip of a soldering iron. Aluminum may be soldered by dipping the parts in the molten solder in the pot or by the application of the soldering iron. The soldering of aluminum may be carried out without the use of flux.

TESTING OF MATERIALS BY MEANS OF ULTRASONICS

A number of systems have been devised for testing materials, particularly metals, for flaws such as hollows, cracks, or other defects of homogeneity.

One of the methods employs the distortion of sand patterns on a steel plate when it is caused to vibrate under the influence of sound. This system can only be applied to

plates in which the sand pattern is known for a perfect plate.

Another system which is particularly useful in that it can be used to detect flaws in a piece of metal of almost any shape is analogous to the echo ranging or depth sounding devices. A quartz crystal projector hydrophone is placed in intimate contact with the metal object to be tested by using a film of oil between crystal and metal. A short pulse of very high-frequency sound (5 megacycles) is sent out by the crystal used as a projector. The reflected pulse is picked up by the crystal used as a hydrophone. The output of the hydrophone is amplified and applied to the screen of a cathode-ray tube. Since all these operations take place in fractions of milliseconds, the electronic switching, etc., is quite intricate and complex. the cathode ray depicts the outgoing pulse and all reflected pulses. From the dimensions and geometry of the piece under test and the velocity of sound in the material and pattern on the oscilloscope it is possible to determine the presence or absence of flaws. This is a very useful and powerful tool. It possesses advantages over X-ray testing in that the particular piece to be tested need not be moved to the apparatus to be tested since the test equipment is quite small and portable. Furthermore, other intervening or adjacent components need not be removed to carry out the tests.

A system for detecting flaws in tires by the use of ultrasonics has been developed. The tire is immersed in water and the transmission of an ultrasonic wave through the tire is obtained by a projector and hydrophone combination. since the characteristic acoustical impedance of rubber and water is practically the same, there will be very little attenuation or other anomalies in the transmission of the ultrasonic wave except in the case of a flaw or defect in the rubber.

ULTRASONIC DELAY LINES AND FILTERS

Delay lines for the storage of pulses one microsecond in length and for periods up to 2000 microseconds have been developed. These delay lines are used for the storage of radar pulses from one pulse to the next. Both mercury and solid lines have been used. Quartz crystal transducers are used for the transmitter and the receiver.

Ultrasonic band-pass filters for use in the intermediate frequency amplifiers in radio receivers consist of mass and compliance elements. Magnetostriction transducers are used for the transmitter and the receiver. The outstanding characteristic is the very high attenuation over a very narrow frequency range at the upper and lower cutoff frequencies. For example, a band-pass filter with a pass band of 6 kilocycles at l00 kilocycles shows 45 decibels attenuation in l kilocycle at the cutoff frequency.

HOW ULTRASONIC NOZZLES WORK

Every ultrasonic nozzle operates at a specific resonant frequency, which is determined primarily by the length of the nozzle. In order to produce standing, sinusoidal longitudinal waves, a necessity for the sustained vibration that produces atomization, the nozzle must be an integral number of half-wavelengths long. This requirement arises because both free ends of a nozzle must be anti-nodes; that is, points of maximum vibrational amplitude. Open-ended organ pipes and chimes are other examples of this

type of wave motion.

The significantly greater amplitude of the standing wave at the atomizing surface end of the nozzle is the result of the amplification of motion provided by the step diameter transition between the large central section of the nozzle and the slender stem that terminates in the atomizing surface.

PRINCIPLES OF ULTRASONIC CLEANING

In general, ultrasonic cleaning consists of immersing a part in a suitable liquid medium, agitating or sonicating that medium with high-frequency (18 to 120 kHz) sound for a brief interval of time (usually a few minutes), rinsing with clean solvent or water, and drying. The mechanism underlying this process is one in which microscopic bubbles in the liquid medium implode or collapse under the pressure of agitation to produce shock waves, which impinge on the surface of the part and, through a scrubbing action, displace or loosen particulate matter from that surface. The process by which these bubbles collapse or implode is known as capitation.

High intensity ultrasonic fields are known to exert powerful forces that are capable of eroding even the hardest surfaces. Quartz, silicon, and alumina, for example, can be etched by prolonged exposure to ultrasonic cavitation, and "cavitation burn" has been encountered following repeated cleaning of glass surfaces. The severity of this erosive effect has, in fact, been known to preclude the use of ultrasonics in the cleaning of some sensitive, delicate components.

Ultrasonic cleaning has, however, been used to great advantage for extremely tenacious deposits, such as corrosion deposits on metals. In any case, cavitation forces can be controlled; thus, given proper selection of critical parameters, ultrasonics can be used successfully in virtually any cleaning application that requires removal of small particulates.

Although the ultrasonic cleaning process has been used for over half a century, no reliable means of quantifying its cavitation activity has ever been developed. Indirect methods of measurement, such as erosion tests on metal surfaces, soil removal from weighted samples, acceleration of chemical reactions, thermodynamic studies, and white noise measurement, have been employed to a limited extent, but none of these methods has proved to be effective.

Cleaning Fluid

It is essential that cleaning fluids be selected on the basis of:

1. The chemical and physical nature of the contaminants to be removed; and

2. The identity of the substrate material.

Insoluble particulate contaminants can, for example, be divided into two groups:

1. Water-wettable or hydrophilic particles, including metal particles, metal oxides, minerals, and inorganic dusts.

2. Non-water-wettable or hydrophobic substances, including plastic particles, smoke and carbon particles,graphite dust, and organic chemical dusts.

Substrate surfaces, too, can be divided into hydrophilic and hydrophobic groups. Rarely are hydrophobic contaminants found on hydrophilic substrates or vice versa, but when this is the case, cleaning is best accomplished simply through rinsing with a suitable solvent. Hydrophilic particles on hydrophilic substrates, on the other hand, are best removed with aqueous detergent solutions, while hydrophobic particles on hydrophobic substrates are most effectively removed by the use of organic solvents.